EXPERIMENTS ON PRODUCING INTENSIVE PROTON BEAMS BY MEANS OF THE METHOD OF CHARGE-EXCHANGE INJECTION

G. I. Budker, G. I. Dimov, and V. G. Dudnikov

The present article provides the results of experiments on accumulating protons along a track with a constant magnetic field by means of the charge-exchange method under resonance conditions. The coherent effects connected with the high intensity were detected and investigated. It was established that the limitation of the orbital current is connected with the action of the longitudinal component of the beam’s electric field.

The experiments described here were performed in the first half of 1966 by means of the device described in [1, 2]. The accumulation of protons was effected by means of the charge-exchange method along an annular track, using a beam of negative hydrogen ions with an intensity of up to 1000 μA.

Figure 1 shows the external view of the device with the annular accumulation chamber, into which an H⁻ beam from a Van de Graaff accelerator was introduced through an ion duct. At the entrance to the accumulating ring, the ion beam had a transverse dimension of 7 mm and an aperture angle of...
Fig. 4. Orbital current (a) and the amplitude of coherent phase oscillations (b). The scale along the horizontal is 500 μsec/cm.

5·10⁻³ rad. The energy scatter of the injected ions did not exceed 0.1%. Figure 2 shows the schematic diagram of the accumulation chamber. The orbital radius is 42 cm, while the operating cross section of the ring is 40 × 80 mm. Before entering the track, the beam passes through a neutralizing target, which consists of a through-flow tube with a diameter of 14 mm and a length of 6 cm, into which carbon dioxide in pulses with a duration of 2 μsec is admitted by means of an electromagnetic valve. The carbon dioxide consumption per pulse is 5·10⁻³ cm³. The chamber, which is provided with tubes at the entrance and exit, has partitions with openings for the beam and is evacuated by means of an N-5 pump through a booster tank with a 20-liter capacity. The through-flow tube does not affect the vacuum in the accumulation chamber. An atomic hydrogen beam with an intensity of up to 500 μA was obtained from this neutralizing target. The charge-exchange hydrogen jet at the orbit, which emerges from a Laval nozzle, is switched on for periods of 800-1000 μsec. It is directed along the radius and enters a receiving tank with a capacity of 800 liters through the receiving cone. The hydrogen discharge amounts to 0.2 mm³ per pulse. After the jet has been triggered, the mean hydrogen pressure in the accumulation chamber increases to 5·10⁻⁴ torr, which, after the scattering of protons, is equivalent to an air pressure of 10⁻¹ torr. The time of hydrogen evacuation from the chamber by means of two N-5 pumps is 0.2 sec. After the charge exchange in the atomic beam in the hydrogen jet, a proton beam with a current of up to 400 μA in the first turn and a duration of up to 1000 μsec was obtained at the orbit. The vertical beam dimension during the first revolution does not exceed 7 mm, while the radial dimension is 10 mm at the antinode and 5-7 mm at the node of the first radial betatron oscillations of protons. The transverse beam position during the first revolution coincides with a circular orbit with an accuracy to 1-2 mm. The angles and the location at which the beam was introduced and also the beam position during the first revolution were controlled by means of quartz screens.

The accumulation of protons was effected under resonance conditions. An accelerating drift tube with an angular dimension of 60° compensated the ionization loss of the proton energy in the hydrogen jet during the accumulation period. The current of circulating protons in the orbit was determined with respect to the rectified signal from a broad-band induction electrode, which had the shape of a through-flight tube, and also with respect to the current of delta-electrons, which were collected at the receiving plate by means of an electric field parallel to the magnetic field. These basic methods of proton current measurement were checked by measuring the charge of protons that are dropped at a certain given time onto the internal target and by measuring the orbital current by means of a Rogowski loop with an integrator. The absolute accuracy in measuring the number of circulating protons was not worse than 20%.